Journal of Psychology and Behavioral Science
December 2019, Vol. 7, No. 2, pp. 109-115
ISSN: 2374-2380 (Print), 2374-2399 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jpbs.v7n2a11
URL: https://doi.org/10.15640/jpbs.v7n2a11

EEG Coherence and Intelligence in Elementary School Children

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Abstract

The EEG and intelligence are measures that describe the children´s abilities and could be a parameter to describe the typical and pathological development. The aim of this research was to describe the relationships between the absolute power and intra-interhemispheric coherence of 10 brain areas with the Intelligence Quotient (IQ) of elementary school children. For that, 12 elementary school children (6 boys) of third grade participated, with an average age of 9 years 5 months, all right-handed and with an IQ equal to or greater than 80, as well as having a normal electroencephalogram. Significant differences were found in the left intra-hemispheric EEG coherence in all bands as well as in the right intra-hemispheric coherence of the Delta band, where the females had higher values in all measurements. The low Verbal Comprehension Index was associated with lower Beta band on the temporal area and the low Processing Speed Index with higher Beta band values. Regardless of whether the intelligence test has a neuropsychological approach, we found associations between the EEG measures and IQ.

Keywords: Electroencephalogram, Coherence, Intelligence, Neuropsychology, Elementary School, Children.

1.Introduction

The concept of intelligence has been studied through various theoretical perspectives, which have facilitated the elaboration of methods to evaluate an individual's ability to comprehend and explain events in their surroundings, this is achieved through their cognitive processes such as perception, language, memory, attention, emotion and language(Checa & Fernández-Berrocal, 2015).According to the psychogenetic perspective, intelligence is the ability to adapt to new situations and it is constructed during early developmental stages from the interaction between the cognitive subject with his environment, and develops from a practical intelligence, associated to the manipulation of objects into a logical intelligence, related to concrete and abstract operations (Piaget, 2016a; 2016b). The American Psychological Association (APA, 2019) defines intelligence as the performance in different tests, the ability to comprehend complex ideas, to adapt to the environment, to learn from experiences, and to find different modes of reasoning in order to overcome any obstacles. This performance is dependent from nutrition, education and generation. Some authors have pointed out that the concept of intelligence has brought forth many controversies, often changing in meaning depending on who is asked, what methods are used to explore it, the level of analysis used, and the values and convictions that are upheld (Gardner, 2001).

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In this way, the intelligence can be assessed, via standardized intelligence quotient (IQ) tests and it is a good predictor for educational outcomes. The IQ of a child is in constant change due to the fact that during the elementary school, children improve their language, acquire new concepts, learn practical, social, Cognitive and affective abilities in the interaction with other children and adults (Breslau, et al., 2001).

Many researches have established the importance of considering the intimate relationship between intelligence and academic performance in interaction with the sociocultural factors in which the child grows, that is, considering cultural diversity in order to overcome bias against different students (Breslau, et al., 2001; Gareca, 2005).Further, intelligence is related with different processes in the brain, where several neurons organize into circuits to process specific kinds of information according to the intended function. According to this, intelligence is a distributed function that depends on the activity of multiple brain regions (Purves, 2001; Goriounova, 2018).Some data have shown in humans, that the grey matter thickness and the activity of temporal and frontal cortical areas correlate with IQ scores, and it has been found that high IQ scores and large temporal cortical thickness are associated with greater and more complex dendrites of pyramidal neurons. In this way, the areas located in frontal and temporal cortices have shown multiple correlations of grey matter thickness and functional activation with IQ scores, specifically, individuals with high IQ have greater grey matter volume in Brodmann areas 21 and 38 (Goriounova, 2018).Also, the human pyramidal neurons of individuals with higher IQ scores sustain faster action potential kinetics during repeated firing. Because of this, intelligence has been associated with neural complexity and efficient information transfer from inputs to outputs within cortical neurons (Goriounova, 2018).According to this, the human brain communicates through synchronized electrical activity, such synchronization facilitates the flow of neuronal information between areas that are concentrated in a neural network, connectivity analyzes are used to describe the neural communication networks necessary for brain functioning (Bowyer, 2016).

There are three main types of connectivity analysis at neuronal level: structural, functional and directed. In structural connectivity, physical connections that occur between different areas of the brain are described; in the functional one, synchronization patterns or correlations between oscillations of the brain electrical activity that are registered during a functional process are analyzed; and in the directed one, the influence that a neuronal pattern has on another one is determined, so this analysis allows to specify the direction of the flow of information in the brain (Bastos &Schoffelen, 2016; Bowyer, 2016).Regarding functional connectivity, coherence is the measure of phase stability between two different time series and is computed by comparing the cross-spectrum with the auto spectrum of EEG signals;this analysis is used to measure connectivity and synchrony between two active EEG electrode sites (Thatcher et al., 2005).Studies that have analyzed the relationship between EEG coherence and intelligence have been interested in discovering the level of synchrony between different brain areas and its relationship with measures of intelligence. It has been reported that coherence is more related to intelligence than other quantitative EEG measures such as absolute and relative power (Jausovec et al., 2000; Thatcher et al., 2005). There is a negative correlation between coherence and intelligence, lower levels of coherence are present in higher IQ levels, especially concerning frontal areas (Thatcher et al., 2005). These results have been interpreted as representing both an increase in neuronal complexity and in specialization, which is reflected in higher IQ scores (Langer et al., 2012). However, other authors have expressed an increase in coherence in higher IQ scores, especially in fronto-parietal conexions during arithmetic calculation and a low relationship between intra-regional connectivity and intelligence (Lee et al., 2012).Moreover, studies made with WISC-R and 19 scalp locations in EEG, found that neural generators synchronize with higher IQ in subjects with ages from 5 to 52 years old (Thatcher et al., 2005). In adults, an increase in Alpha band power has been reported with high IQ scores, and in comparison to other electroencephalographic bands, there is evidence that the Alpha band is more positively correlated with intelligence, which is possibly due to a genetic basis (Posthuma et al., 2001). In children with low IQ, a decrease in Delta band power and increase in Alpha band power has been reported (Liu et al., 2008).On the other hand, the sexual dimorphism of the developing brain is still unclear and is limited because it depends from many factors even if the EEG is not recorded during cognitive task (Etchell et al., 2018).There is data of strong correlations between left intra-hemispheric values and intelligence scores in working memory and verbal execution (Fonseca et al., 2006; Lee et al., 2012), and lower coherences in a female population averaging 20 years of age (Thatcher et al., 2005).Considering the aforementioned, the aim of this research was to describe the relationships between the absolute power and intra-interhemispheric coherence by sex, of 10 brain areas with the IQ of elementary school children.

2. Methods

2.1 Subjects

Subjects consisted of 12 elementary school aged children (6 males) of third grade, with an average age of 9 years 5 months, all right-handed and with an Intelligence Quotient (IQ) equal to or greater than 80, as well as having a normal electroencephalogram. All children were currently enrolled in a public elementary school in the city of Xalapa, Veracruz, Mexico at the time of their neuropsychological assessment. Other requirements consider a letter of consent signed by the parents or tutors which included details of the study, such as the objective, characteristics, and non-invasive methods used. The exclusion criteriawere: children with Intelligence Quotient (IQ) less than 80 and abnormal electroencephalogram. This test protocol was evaluated by an ethics committee and was approved with the number CONBIOÉTICA 30CE100120180131, also the parents and children signed an informed consent.

2.2 Instruments and procedures

All subjects were assessed with the Weschler Intelligence Scale for Children, Fourth Edition (WISC-IV), which has been standardized for the Mexican population. This study used various categories regarding intelligence that the WISC-IV reports, including Full Scale Intelligence Quotient (FSIQ), and the Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), and Processing Speed Index (PSI) for each subject (Weschler, 2003).Natural scores were converted into scaled scores according to the norms and tables contained within the WISC-IV manual (Weschler, 2003) and FSIQ scores were obtained through classification of percentiles according to what the test establishes: $\geq$ 130, Very Superior (VS); 120 to 129, Superior (S); 110 to 119, Above Average (AA); 90 to 109, Average (A); 80 to 89, Below Average (BA); 70 to 79, Borderline (B); and $\leq$ 69, Very Low (VL).EEG recordings were obtained during a resting eyes-closed state using Synamps RT amplifiers and Curry 7 software, using 64 active channels: FP1-FP2, AF3-AF4, F1-F2, F3-F4, F5-F6, F7-F8, FT7-FT8, FC1-FC2, FC3-FC4, FC5-FC6, C1-C2, C3-C4, C5-C6, T7-T8, TP7-TP8, CP1-CP2, CP3-CP4, CP5-CP6, P1-P2, P3-P4, P5-P6, P7-P8, PO3-PO4, PO5-PO6, PO7-PO8, CB1-CB2, O1-O2, FPZ, FZ, FCZ, CZ, CPZ, PZ, POZ and OZ. Three bipolar channels were used to monitor horizontal and vertical eye movements as well as cardiac activity and all had impedances below 5 k**Ω**. Offline rereferencing to mastoids (M1 and M2) was done.

From each EEG recording,30 artifact free samples of 2 seconds were collected, with the purpose of calculating absolute and relative power (AP and RP, respectively) from each of the active electrodes, as well as four frequencies: Delta (0.1-3 Hz), Theta (3.5-8 Hz), Alpha (8.5-12 Hz) and Beta (12.5-30 Hz). Averaging various channels, 10 areas were obtained: Right Frontal (RF):Fp2, F2, F4, F6, F8, AF4, FT8, FC2, FC4, FC6; Left Frontal (LF): Fp1,F1, F3, F5, F7, AF3, FT7, FC1, FC3, FC5; Anterior Sagittal (AS):Fz, FCz; Central Sagittal (CS):Cz, Pz, FPz; Right Temporo-parietal (RTP):T4, T8, C2, C4, C6, CP2, CP4, CP6, P2, P4, P6, P8; Left Temporo-Parietal (LTP): T3, T7, C1, C3, C5, CP1, CP3, CP5, P1, P3, P5, P7; Right Temporal (RT): T4, T6, TP8; Left Temporal (LT): T3, T5, TP7; Right Occipital (RO): O2, and Left occipital (LO):O1.

For intra-inter hemispheric coherence, values were calculated between electrodes that were separated by at least 3 cm in order to control the effects of volume conduction (Nunez, et al, 1999). These values were averaged to obtain three different areas of analysis: Right Intra-Hemispheric Coherence, Left Intra-Hemispheric Coherence, and Inter-hemispheric Coherence. All procedures and evaluations were made in the Laboratorio de Psicobiologiaat Universidad Veracruzana, in a stimulus-free cubicle during two separate sessions, lasting around 90 minutes each.

2.3 Statistical Analysis

For the statistical analysis the variables of intelligence: Full Scale Intelligence Quotient(FSIQ)and the different indexes, absolute power, relative power and intra-interhemispheric coherence averages were compared.EEG data was normalized. The association between intelligence variables and quantitative EEG data, including absolute and relative power as well as coherence, was found through an ANOVA realized in the software JMP 10, carrying out the analysis within sex and between sexes.

3. Results

Two different groups were formed according to their WISC- IV intelligence test scores, 6 having an average IQ and 6 having a below average FSIQ. The mean for the average FSIQ group was 96, while the mean of the below average FSIQ group was 82. According to differences between sex, females obtained an average FSIQ of 90 and males obtained a FSIQ of 88. The average FSIQ was 89, while 88 was the average score for the Perceptual Reasoning and Working Memory indexes and 92 for the Processing Speed index. The results of the EEG analysis indicate that during the resting state there was greater percentage of Alpha activity (36%), followed by Delta (33%), and Theta (23%), ending with Beta activity (7%).

In the analysis of Absolute Power (AP), the average was greater in the Alpha Band in right and left occipital areas (75.32 $\mu V^2/Hz$ and 62.03 $\mu V^2/Hz$, respectively) and lower in the Beta band concerning all regions (1.3 $\mu V^2/Hz$). Comparing AP with FSIQ groups, there were significative differences in the Beta band of right occipital areas ($F = 6.899$, $df = 1,10$, $p = 0.025$). There were also significant differences: concerning the Beta band of the right frontal region and the VCI ($F= 4.500$, $df = 3,8$, $p = 0.03$) where low VCI scores were associated with low Beta band values; Beta band of the temporal area was also different, indicating an association between low PSI scores and higher Beta band values($F = 4.352$, $df = 3,8$, $p = 0.04$).In the comparison of AP and RP with Cerebral Coherence and Intelligence, we did not find statistically significant differences, but we found that the average RP was higher in the Delta Band and lower in the Beta Band in all brain areas (Table 1). According to sex of the subjects, the males had higher RP in Beta, Delta and Theta (4.02, 41.52 and 29.49 respectively) than females (2.65, 41.10 and 28.16 respectively), while females showed greater RP in Alfa band (6.28) than males (24.95) (Table 2).

Table 1. Averages of AP and RP of each frequency band in ten brain areas.

Frequency Band	**ALPHA**		**BETA**		**DELTA**		**THETA**	
Area	AP	RP	AP	RP	AP	RP	AP	RP
Left Frontal	10.47	28.46	1.08	2.26	21.16	41.76	11.01	27.50
Right Frontal	10.33	29.25	1.14	2.89	15.91	44.01	11.07	23.82
Anterior Sagittal	18.52	31.01	0.96	2.46	24.98	35.56	21.92	30.95
Central Sagittal	21.07	30.55	1.04	1.57	22.59	37.34	16.72	30.52
Left Temporo-parietal	26.01	24.61	1.19	4.26	19.96	41.67	15.60	29.44
Right Temporo-parietal	33.13	26.29	1.30	2.78	25.24	41.79	19.45	29.12
Left Temporal	28.04	21.59	1.35	6.52	19.19	42.92	14.17	28.94
Right Temporal	28.20	26.15	1.23	3.05	20.35	42.33	17.41	28.44
Left Occipital	62.03	21.84	1.73	2.55	36.19	46.95	26.57	28.65
Right Occipital	75.32	25.34	1.89	5.01	39.63	38.75	28.20	30.89

Note: AP = Absolute Power; RP = Relative Power

Table 2. Averages of AP and RP of each band of frequency brain by sex of subjects

Frequency Band Sex	**ALPHA**		**BETA**		**DELTA**		**THETA**	
	AP	RP	AP	RP	AP	RP	AP	RP
Female	28.00	28.06	1.30	2.65	25.44	41.10	18.58	28.16
Male	34.59	24.95	1.28	4.02	23.01	41.52	17.84	29.49

Note: AP = Absolute Power; RP = Relative Power

When comparing coherence averages by sex, significant differences were found in left intra-hemispheric coherence in the Alpha ($F = 5.505$, $df = 1,10$, $p = 0.049$), Beta ($F = 12.228$, $df = 1,10$, $p = 0.005$), Delta ($F = 26.086$, $df = 1,10$, $p < 0.001$) and Theta bands ($F = 13.347$, $df = 1,10$, $p = 0.004$), as females had higher values than males. There were also significant differences for right intra-hemispheric Beta band coherence ($F = 7.553$, $df = 1,10$, $p = 0.020$) and right intra-hemispheric Delta band coherence ($F = 5.756$, $df = 1,10$, $p = 0.03$), as females had higher values as well (Figure 1).

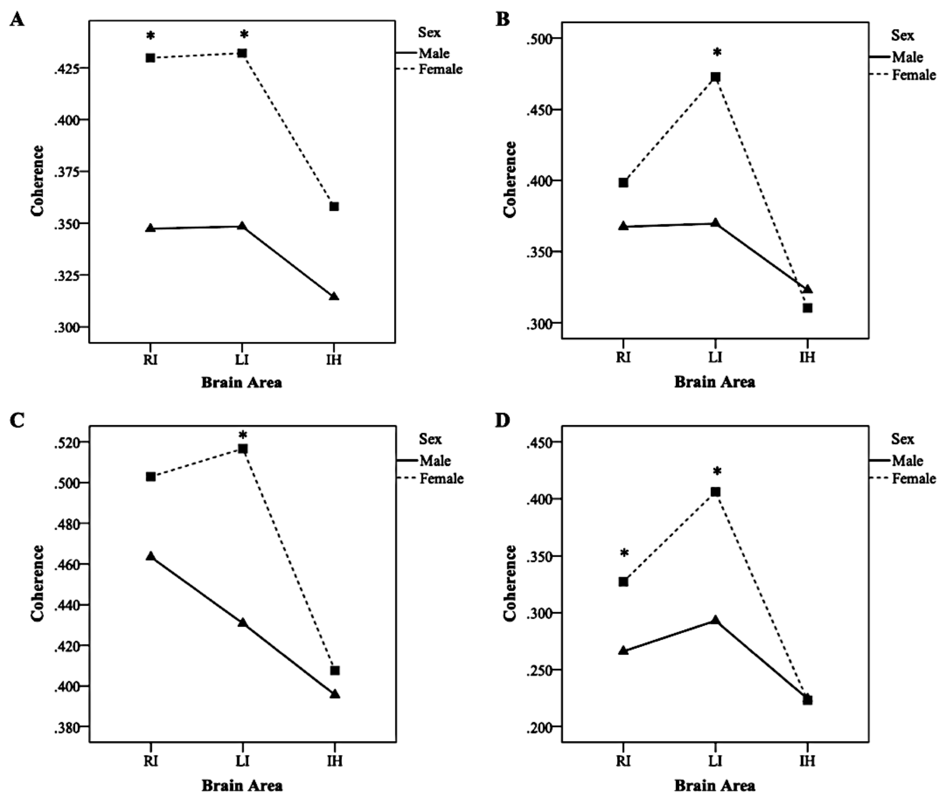

Figure 1. Coherence for males and females in each frequency bands in the right intra-hemispheric (RI), left intra-hemispheric (LI), and inter-hemispheric (IH) areas. Delta (A), Theta (B), Alpha (C), Beta (D) bands, * indicate significant differences $p < 0.05$.

The comparison between coherence and the intelligence index VCI resulted in significant differences between left intra-hemispheric Alpha band coherence in males ($F = 34.727$, df = 3,2, $p = 0.02$) with higher coherence values relating to lower VCI scores. Significant differences were also found when comparing FSIQ scores with left intra-hemispheric Theta coherence ($F = 8.2577$, df = 3,2, $p = 0.04$), as higher coherence values yielded to higher FSIQ. When comparing left intra-hemispheric Delta band coherences with PSI scores, it was found that borderline PSI scores had higher coherences than those with average PSI scores ($F = 11.511$, df = 3,2, $p = 0.02$).Finally, when comparing inter-hemispheric Beta band in males with FSIQ, significant differences were found ($F = 16.208$, df = 1,4, $p = 0.01$), in which higher coherence values corresponded to higher FSIQ.

4. Discussion

The concept of intelligence is a parameter to define the abilities of people, and it has been the subject of debate since it was established as a measurement since it points out the abilities of an individual compared to people of the same age, but this ability can vary according to the nutritional status, type of education and cultural context, because the experiences with technological advances differ between times (APA, 2019).However, relevant contributions have been found with populations of different ages, in terms of the associations between the IQ and the features of the electroencephalographic activity, because of this, in this investigation we considered to describe the relationship between coherence and intelligence measure, since it has been observed that IQ scores and morphology of the human pyramidal neurons correlate (Thatcher et al., 2005, 2007; Langer, et al., 2012; Goriounova, 2018). These associations were observed in Mexican schoolchildren with the current version of the Weschler scale (WISC-IV) that integrates the exploration of intelligence through the state of neuropsychological functions. As known, the EEG has a high temporary resolution and a limited spatial resolution. The last one is determined by the number of electrodes (Cohen, 2014), therefore, increasing the number of electrodes allows researchers and clinicians to better locate areas of interest, either when searching for connectivity between brain areas or when locating epileptic foci (Sohrabpour et al., 2015), for that reason in this research, we used 64 electrodes, because some authors recommend at least this number (Ryynänen et al., 2004).The total IQ average was similar by sex.

Regarding the baseline activity of the resting EEG, the expected parameters for age and EEG state condition were observed, since Alpha activity prevailed in bilateral occipital areas, although there was a high percentage of Delta and Theta activity too, it could be due to the presence of drowsiness during registration. The aim proposed in order to describe the relationships between the absolute power and intra-interhemispheric coherence by sex, of 10 brain areas with the IQ of elementary school children, was partially fulfilled, since we observed significant differences between the left intra-hemispheric coherence in all bands as well as in the right intra-hemispheric coherence of the Delta band, because the females had higher values in all measurements, which coincides with Barry, Clarke, McCarthy, Selikowitz, Johnstone and Rushby (2004) who described, that in males the coherence develops later than females. It will be necessary to further analyze what factors determine the differences found, because several studies conducted with children of similar ages to those of the participants, indicate that the differences are not relevant because it is difficult to determine if they are the cause or consequence of certain behavior, with greater reason if the analysis is done in resting state EEG (Etchell et al., 2018). To determine the importance of gender differences, it will be necessary to document and control the level of stimulation in the family and educational context from each child. The differences found between the areas of WISC-IV in Verbal Comprehension Index and Processing Speed Index with Beta band values could be interpreted as Thatcher, North &Biver (2005) mentioned like neuronal complexity and specialization in cognitive functions. Nevertheless, of whether the intelligence test has a neuropsychological approach, we found associations between the EEG and IQ. It will be necessary to analyze if in a larger sample it is confirmed in children whose principal language is the Spanish.

Acknowledgments: CONACYT for the PhD Scholarships No. 717999 and No. 752365

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